High Sensitivity Search for $\bar{\nu}_e$'s from the Sun and Other Sources at KamLAND

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Of the many mechanisms that have been suggested to explain the solar neutrino problem [1], neutrino oscillations are strongly favored by the data from solar neutrino experiments and from the recent observation of reactor $\bar{\nu}_e$ disappearance by the Kamioka Liquid Scintillator Anti-Neutrino Detector (KamLAND) [2]. However, the limited precision of current measurements still allows for the possibility that other mechanisms play a sub-dominant role. There are several conceivable mechanisms which would lead to a $\bar{\nu}_e$ component in the solar flux incident on Earth. Electron neutrinos with a non-zero transition magnetic moment can evolve into $\bar{\nu}_\mu$'s or $\bar{\nu}_\tau$'s while propagating through intense magnetic fields in the solar core. These neutrinos can, in turn, evolve into $\bar{\nu}_e$'s via flavor oscillations. There is also neutrino decay, in which a heavy neutrino mass eigenstate decays into a lighter anti-neutrino mass eigenstate. In addition to the Sun, other exotic sources of $\bar{\nu}_e$'s include Weakly Interacting Massive Particle (WIMP) annihilation in the Sun and Earth and relic supernova neutrinos, either of which could contribute to a continuous $\bar{\nu}_e$ flux. The KamLAND experiment has recently performed a search for $\bar{\nu}_e$'s from the Sun and other sources [3].

Details of the KamLAND experiment can be found in [2, 3] and elsewhere in these reports. KamLAND detects $\bar{\nu}_e$ via the inverse β–decay reaction $\bar{\nu}_\mathrm{e} + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}$ consisting of a prompt energy deposit from the positron and two annihilation γ's followed $\sim$210 μs later by neutron capture on hydrogen, producing a 2.2 MeV γ. The $\bar{\nu}_e$ energy was deduced from the prompt energy E_{prompt} using the relationship $\mathrm{E}_{\bar{\nu}_e} = \mathrm{E}_{prompt} + \mathrm{E}_{recoil} + 0.8\,\mathrm{MeV}$, where the small quantity E_{recoil} refers to the neutron kinetic energy in the final state and was neglected. KamLAND was designed to study the flux of reactor $\bar{\nu}_e$'s. While the reactor $\bar{\nu}_e$ flux spectrum has an endpoint of $\sim$ 8.5 MeV, the ^{8}B solar neutrino flux spectrum extends well beyond this energy to $\sim$ 15 MeV. As a result, KamLAND data may be used to search for $\bar{\nu}_e$'s in the solar neutrino flux over an energy range largely free of reactor $\bar{\nu}_e$ events. Events with 8.3 MeV $< E_{\bar{\nu}_e} <$ 14.8 MeV, followed 0.5 μs $-$ 660 μs later by a spatially correlated delayed event depositing between 1.8 MeV and 2.6 MeV of energy, were selected. Both the prompt and delayed events were constrained to be within 550 cm of the detector center in order to suppress backgrounds due to natural radioactivity and muon spallation. Backgrounds were further reduced by discarding $\bar{\nu}_e$ candidates associated with detected muons. Taking into account the 12% deadtime associated with muon rejection, the total sample livetime, corresponding to the period March 4 - December 1, 2002, was 185.5 days and the exposure of this measurement corresponds to 0.28 kton-year.

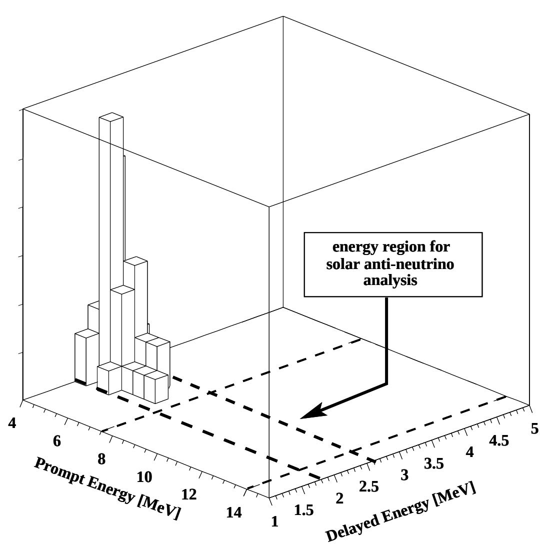

FIG. 1: Energy distribution of the final event candidates. The tail from reactor $\bar{\nu}_e$ events is visible below 8 MeV.

Figure 1 shows the delayed versus prompt energy distribution for events after all selection cuts, except those on the prompt and delayed energies themselves. No events were observed in the signal region. The number of background events in this is signal region expected to be 1.1$\pm$0.4 events where the primary background source is from muon spallation products that leak through the muon veto cuts. This result can be used to obtain a limit on $\bar{\nu}_e$ fluxes of any origin. Assuming that all $\bar{\nu}_e$ flux has its origin in the Sun and has the characteristic ^{8}B solar ν_e energy spectrum, we obtain an upper limit of 3.7×10^2 cm^{-2} s^{-1} (90% C.L.) on the $\bar{\nu}_e$ flux. Normalizing to the standard solar model ^{8}B ν_e flux in the analysis energy window, this flux limit corresponds to an upper limit on the neutrino conversion probability of 2.8×10^{-4} at the 90% C.L. and represents a factor of 30 improvement over the best previous measurement [4].

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